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THERMAL INTENSITY AND THE AREA OF STIMULUS[1]

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At present the formulation of a general rule expressing the relation of sensational intensity to the area of stimulus seems to be impracticable. The obvious reason is the lack of uniformity in the facts; and this lack appears to arise from the diversity of organic conditions within the several senses. The spread or multiplication of a tactual stimulus upon the skin is different from the areal increase of light upon the retina, and both offer a mode of attack upon the organism which is again unlike that sustained under the numerical increase of tones or noises. The problem itself may indeed be given a single formulation, namely: does an areal or numerical increase of stimulus produce an intensive increment in sensation? But the solution must be sought separately in the individual departments of sense. And first of all, we must distinguish between those cases where the increase of stimulus leads to qualitative increase in sensation (*e. g.*, the musical chord) and those where it produces a like quality of different locality or different extent (*e. g.*, the spread of a tactual or gustatory stimulus). The problem under consideration falls within the second group of cases.

Stumpf[2] found occasion to discuss the matter in his analysis of tonal fusion. He divides the question into two parts, which he states as follows: first, 'is the intensity of a tone affected by the presence in consciousness of other tones?' and secondly, 'is a tonal complex stronger than each of its constituent tones?'

[1]From the psychological laboratory of Cornell University.
[2]*Tonpsychologie*, ii, 1890, 416 ff.

In answer to the first question, Stumpf asserts that the individual tone is diminished, not augmented, by the presence of other tones; and that the decrease in intensity is a true weakening, not a phenomenon of attention. Heymans has since maintained that intensive 'inhibition' is general among sensory processes.[1] In answer to the second question, Stumpf denies the intensive summation of different tones. Two tones of like strength may be fuller, richer, or more 'voluminous' than one, but not stronger.

In vision, the matter is more complicated. Here one must inquire (a) whether binocular intensity is greater or less than monocular; (b) whether two disparate retinal areas, either of the same or of different eyes, produce an interactive effect upon intensity; and finally, (c) whether the enlargement of a single stimulus-area affects the strength of the resultant sensation. The facts are further complicated for vision by the peculiar relations of intensive to qualitative change. The dependence of visual sensation upon area appears in such problems as the spatial limen for colors and the sensitivity of peripheral vision, and in the facts of contrast and induction.

The intensity of pressure is obviously dependent upon the size of stimulus. But the mechanics of deformation plays an important part in determining the excitation of the tactual organs.[2] Von Frey found that the stimulus limen for moderate areas is approximately proportional to the surface affected and he lays it down that the neural excitation is a function of hydrostatic pressure. Brückner, who stimulated neighboring pressure-organs with the blunt end of a fine needle, found evidences of physiological (central) summation under simultaneous stimulation, even where the two points were discriminated.[3]

As regards temperature, the traditional view correlates the size of a heated or cooled area upon the skin with the intensity of the resulting warmth or cold sensation. This view is frequently supported by the observation that the finger plunged into warm or cold water gives a weaker sensation than the immersion of the whole hand or the entire body.[4] The experience itself is undeniable. But whether the observation may safely be interpreted to mean that the higher

[1]G. Heymans: Untersuch. ueber psychische Hemmung, *Zeitschr. f. Psych. u. Physiol. d. Sinnesorgane*, XXI, 321; XXVI, 305; XXXIV, 15; XLI, 28, 89.

[2]V. Frey, M.: *Untersuch. u. d. Sinnesfunction. der menschlichen Haut*, 1896.

[3]A. Brückner: Die Raumschwelle bei Simultanreizung, *Zeitschr. f. Psych. u. Physiol. d. Sinnesorgane*, XXVI, 1901, 33.

[4]*E. g.*, E. H. Weber in Wagner's *Handwörterbuch der Physiol.*, iii, 2, 553. Weber explains in terms of cerebral summation. *Cf.* Stumpf, *Tonpsych.*, ii, 1890, 445.

intensity rests directly upon the exposure of a larger area is doubtful. It may rest upon (1) adaptation, (2) an augmentation of sensory feeling, (3) the presence or absence of such organic accompaniments as shiver, goose-flesh, or visceral displacement, (4) the addition of highly tuned temperature-organs, (5) the confusion of extent with intensity, (6) the confusion of pressure with temperature, or finally (7) the difference in cutaneous conduction over large and small extents.

The four methods used in our experiments were designed to test these various possibilities.

Method I. Immersion

The observer's eight fingers were ringed with indelible ink ½ inch and 2 inches from the tips. The forearm was supported, and the hand was allowed to hang down in a natural position. Water was kept at a constant temperature (45° C.) in a small vessel, and the vessel was raised by the experimenter until the water reached either the first or the second ring upon a single finger. The observer was not required to move his hand or fingers. Immersion lasted one second. After it, the finger was dried gently and without friction, by applying an absorbent cloth. Then the same or another finger was immersed in the same way up to the second or first ring. The usual precautions against the constant errors of space and time were taken. The observer was asked to report which sensation was the stronger. Preliminary trials were made in which the danger of confusing extent and intensity was impressed upon him. In all but two out of forty-eight experiments, the two trained observers (H. and S.) reported an intenser warmth from immersion of the larger surface. This result confirms common observation; while, at the same time, the method makes it clear that the judgment of difference rests neither upon the repeated use of a common part-area (adaptation) nor upon the temporal order of comparison. Furthermore, the introspections indicate that the judgments were true comparisons of intensity, not of area. It is possible, however, that the finger-tips are uniformly less sensitive to warmth than the rest of the hand, and that the results reached under Method I. are to be referred to this difference. To eliminate this possibility, and also the strong suggestion of degree that arises from gradual immersion, a new method was devised.

Method II. Circular Areas

An area 3.5 x 4.0 cm. was laid off on the palm of the hand or on the volar forearm and stimulated, under the procedure of paired comparisons, by a graded series of five brass cylinders, all of the same weight, and of diameters which ranged from

1.4 cm. to 3.3 cm. The cylinders stood at 5° C. (cold stimulus). Their flat circular ends were set down at all parts of the chosen rectangular area mapped upon the skin, so that the same temperature organs should be brought into function, in the course of the experiments, by both large and small cylinders. Altogether, 24 series of 10 comparisons each were made with three observers (H., S., and F.). Of the 240 comparisons, 170 (70%) gave an intenser cold with the larger areal stimulus (72%, 72%, and 67%, by observers).

The methods of immersion and circular areas have reduced our list of possibilities as follows. (1) Adaptation is eliminated by the successive stimulation of different areas, (2) affective indifference is secured by the use of small areas and of moderate intensities of stimulus, (3) organic complexes are avoided by the same means, (4) inequalities of "tuning" are partially compensated by the distribution of stimuli over a common field of exploration (method of circular areas), and (5) and(6) the confusion of thermal intensity with extent and with pressure is avoided by practice-series carried out under definite instructions.

The fourth possibility is only partially provided against; for the chances that a large stimulus will strike a highly tuned region exceed the chances for a small stimulus. And the greater physiological efficacy of a large stimulus through conduction (7) may account for the greater intensity of the large sensation. Let us first consider the fourth possibility.

Method III. Weak and Strong Areas

The direct comparison of areas of high and low sensitivity seemed to us the simplest way of arriving at the value of tuning in areal stimulation. So we selected a region upon the upper arm which gave, under the cylinders, a bright lively cold and an intensive warmth, and we then instituted a one-to-one comparison between it and a dull region on the ulnar side of the palm. Forearm and forehead were similarly compared. The smallest of the five cylinders was used upon the place of high sensitivity,—designated I_1 (cylinder-1 on intensive area),—and all the cylinders were compared with it, in haphazard order, upon the weak area (designated W_1, W_2, . . . W_5).

The number of intensive judgments in which the *small-strong* area was sensed as colder (or warmer) than any one of the *large-weak* areas is set down in Table I. The initials of the Obs. are written at the top. Each place in the columns represents a total of six judgments. Thus I_1 was pronounced "warmer" than W_1 (the same stimulus set on a weak-warm area) 47 times out of a total of $6 \times 9 = 54$; I_1 "colder" than W_1

TABLE I

WARM	H			S				F		Total	COLD	H		S				F		Total
$I_1 > W_1$	4	6	6	4	3	6	6	6	6	47	$I_1 > W_1$	6	6	4	6	6	6	5	5	44
$I_1 > W_2$	4	6	3	2	3	5	5	3	6	37	$I_1 > W_2$	6	6	1	3	5	3	3	4	31
$I_1 > W_3$	4	2	2	1	2	4	5	3	3	26	$I_1 > W_3$	2	5	0	2	3	5	2	2	21
$I_1 > W_4$	3	3	2	0	0	4	4	4	2	22	$I_1 > W_4$	3	2	3	0	3	4	2	4	21
$I_1 > W_5$	2	1	2	0	0	2	4	2	2	15	$I_1 > W_5$	1	2	3	1	1	2	2	2	14

(weak-cold area) 44 times out of a total of 6 x 8 = 48. But $I_1 > W_5 = \frac{15}{54}$ (warm) and $\frac{14}{48}$ (cold). Although equality-judgments were discouraged by the instructions and therefore appeared but rarely, it will be seen from the Table that subjective equality lies just above W_3; $\frac{26}{54}$ and $\frac{21}{48}$; *i. e.*, the thermal intensity from a cylinder 1.4 cm. diameter set in one certain region of high sensitivity is approximately equal to the thermal intensity from a cylinder of 2 cm. diameter applied to a certain other region of low sensitivity.

Thus the fourth item in our list of possibilities is accounted for by the discovery that a large area of low tuning can actually be made equal for sensation to a small area of higher sensitivity.

The seventh item is left. Size of stimulus seems clearly to be translatable into intensity of sensation. It remains, however, to be seen whether the translation is due to a process of summation or to the different conduction through the skin of large and small stimuli. The obvious recourse is to the individual sense-organ for cold and warmth.

METHOD IV. TEMPERATURE SPOTS

Three separate organs for cold were found within the radius of a few millimeters upon the volar forearm. A like group of warm-organs was also identified and mapped in the same general region. The organs in the cold group were designated as *a*, *b*, and *c*, those in the warm group as *a'*, *b'*, and *c'*. They were explored with blunt pointed temperature-cylinders held at approximately a constant temperature (water at 5° and 45° C). Again, we proceeded with paired comparisons, taking one organ with one, and one with two. Thus the intensity of each sensation was compared with that from the other two organs, taken singly and also together. The simultaneous stimulation of two spots was effected by the use of a double v. Frey stimulator, in which the bristles were replaced by smooth blunt copper wires of 1-mm. diameter. Adaptation was avoided by taking each organ only once in any comparison;

thus *a* was compared with *b* and *c*, never directly with *a* or *ab* or *ac*.

The following Table (II) gives the results of 515 experiments from three observers (initials at the left)for cold and warmth. The columns show the number of times each of the

TABLE II

	COLD								WARM							
	a ≷ b		a ≷ c		b ≷ c		Totals		a′ ≷ b′		a′ ≷ c′		b ≷ c′		Totals	
H	20	10	25	5	23	6	89		15	8	22	2	14	9	70	
S	20	12	28	4	21	11	96		12	4	13	2	10	6	47	
F	15	9	21	2	15	8	70		9	7	15	1	13	3	48	
	55	31	74	11	59	25	255		36	19	50	5	37	18	165	420
%	64	36	87	13	70	30		%	65	35	91	9	67	33		
	ac ≷ b		a ≷ bc		ab ≷ c				a′c′ ≷ b′		a′ ≷ b′c′		a′b′ ≷ c′			
H	4	2	3	3	5	1	18		4	1	2	4	4	2	17	
S	3	3	3	3	5	1	18		4	0	2	2	4	0	12	
F	3	3	4	2	4	2	18		2	2	3	1	4	0	12	
	10	8	10	8	14	4	54		10	3	7	7	12	2	41	95
%	56	44	56	44	78	22	309	%	77	23	50	50	86	14	206	515

three temperature organs in the group returned the intenser sensation. Thus in thirty *a-b* comparisons, H. judged *a* colder twenty times, *b* colder ten times. In twenty-three *a′-b′* comparisons, H. judged *a′* warmer fifteen times, *b′* warmer eight times. Totals, recorded both in numbers and in percentages for each comparison, are added at the bottom. The last half of the Table gives the results for the one-to-two comparisons. Thus H. judged *ac* taken together colder than *b* four times out of six, and *a′ c′* warmer than *b′* four times out of five.

The relative tuning of the sense-organs is indicated by the following results; *a* was pronounced colder than *b* or *c* (taken singly) in 75.5% of the comparisons made, and *a′* warmer than *b′* or *c′* in 78%. The corresponding numbers for the other spots stand; $b = 53\%$, $b' = 51\%$, $c = 21.5\%$, $c' = 21\%$. Thus it becomes evident that the differences in tuning are considerable. The following order of sensory intensity may therefore be set down; *a* (or *a′*) $>$ *b* (or *b′*) $>$ *c* (or *c′*).

Now we are in a position to discover whether reenforcement of one sense-organ by another occurs. If it does occur, we might expect to find $ac > a$ when both are compared with b, $bc > b$ when compared with a, etc. The one-to-one and the one-to-two comparisons are brought together in Table III.

TABLE III

COLD	%DIFF.	WARM	%DIFF.
A > A (b)	9	A′ > A′ (b′)	5
A > A (c)	8	A′ (c′) > A′	12
B (c) > B	8	B′ (c′) > B′	15
(A) b > b	8	(A′) b′ > b′	19
(B) c > c	31	(B′) c′ > c′	41
(A) c > c	26	(A′) c′ > c′	44

The upper half of the Table shows the result of adding a second, *weaker* sense-organ to a first, stronger; the lower half, the result of adding a second *stronger* organ to a weaker first. For the sake of clearness, the stronger component is indicated by a capital letter, and the third letter added—in the one-to-two comparisons—is enclosed in parentheses.

It will be seen (upper half) that b or c (weak spots) added to A, or c added to B, decreases as often as it increases (3 to 3) the relative intensity of the cold or warmth; but that, on the other hand, the addition of a more highly tuned organ (lower half) to b or c invariably raises the intensity of the sensation. We are led to infer, therefore, that under the given conditions no sensible process of summation takes place; that the intensity of the temperature sensation is determined, instead, by the most highly responsive component in the excitation. This law may not obtain, of course, where two or more thermal areas are separately localized. Even within the narrow limits of a cylinder-area (Method II) the observers noted at times a plurality of colds or of warmths of unequal degree.

The apparent summation under our cylinders is very likely a matter of conduction. The excitation-value of a 1.5-cm. cylinder is different from that of one 3-cm. in diameter. In the first place, the thermal gradients from centre to periphery are unequal; and in the second place, the difference in temperature between the skin and the stimulus will naturally be

more quickly reduced with the stimulus of smaller area.[1] Our punctiform stimulus of constant area (Method III) eliminates both of these complicating factors.

Temperature-sensations seem to stand, then, as regards intensity, in the same case as tones. Without analysis, that excitatory factor which possesses the highest valence determines the intensity of the sensation. With (local) analysis, it seems probable that each mental constituent appears in approximately its own proper strength. Whether mutual 'inhibition,' however, tends slightly to blunt the constituent intensities under analysis, our results do not clearly inform us.

SUMMARY. The common observation that large surfaces are sensed as colder or warmer than small suggests that thermal intensity may be a function of the *number* of temperature-organs stimulated. But in working with individual end-organs we found no evidence of summation; we found, instead, that the strength of sensation is primarily determined by the most highly tuned of the organs involved. Tuning does not, however, wholly explain the common observation. After the consideration of six other possible factors, we conclude that the high intensity of the 'large' sensation is also owing, in part, to the more favorable conditions afforded by the stimulus of great area for conduction from the surface of the body to the true organs for temperature.

[1]In order to demonstrate the difference of conduction we proceeded as follows. An ordinary thermometer reading to $\frac{1}{10}$° C. was laid upon a flat horizontal surface. A sheet of cardboard with a thickness slightly in excess of that of the lower end of the thermometer was cut to receive the bulb. Then a strip of pliable lamb's leather was stretched over both and tacked in place. The mercury bulb represented the organs of temperature and the leather the cuticle of the skin. The thermometer was brought to the temperature of the room (23.5°) and the five cylinders used in Methods II. and III. were brought to zero, and then applied in succession to the leather sheet just over the bulb. Each cylinder remained upon the leather for one minute, during which thermometric readings were taken every five seconds. The rate of drop in temperature accorded with the size of the cylinder, as is shown by the final readings, which stand for cylinders 1 (smallest) to 5 (largest): 1.6°, 2.1°, 2.7°, 2,9°, and 3.0°. The whole course of the twelve readings for each cylinder (every 5 sec. for 1 min.), when platted, also showed in a very striking way the difference *in physiological efficiency* of the five brass areas standing at one and the same temperature. A repetition of the observations indicated that the differences fell well within the probable error of observation. To make sure that the thermal gradient from centre to periphery is likewise a function of the size of stimulus, we took similar sets of readings with the bulb set directly under (1) the centre, (2) the middle of a radius, and (3) the margin of cylinder 5, and under (1) the centre, and (2) the margin of cylinder 1. The averages of two sets of final readings (initial temperature 21.°) were the following: for cyl. 5, (1) 1.85° ± .15, (2) 1.7° ± .10, (3) 1.15° ±.05; for cyl. 1, (1) 1.2° ± 0, (3) 1.0 ± 0. Thus it appears, even from our rough method of determination, first, that the total conductivity of the different areas is different, and secondly, that conduction within one and the same stimulus-area varies from centre to margin.